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NORTH DIVERSION STRUCTURE ALBUQUERQUE NEW MEXICO

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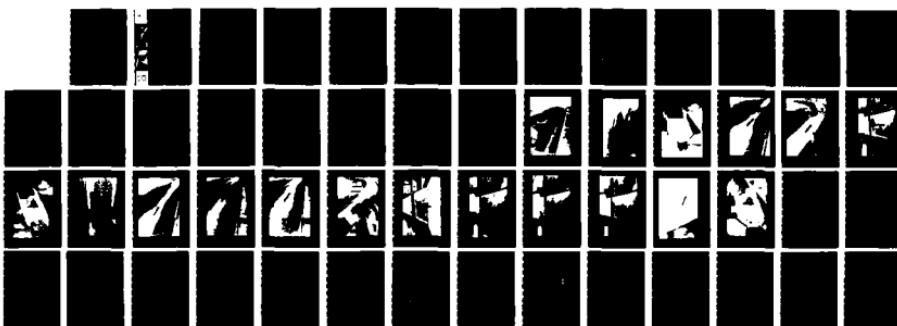
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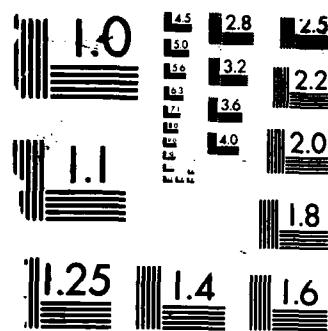
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NORTH DIVERSION STRUCTURE ALBUQUERQUE, NEW MEXICO

Hydraulic Model Investigation

by

Charles H. Tate, Jr.

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631



May 1987
Final Report

Approved For Public Release; Distribution Unlimited

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Prepared for US Army Engineer District, Albuquerque
Albuquerque, New Mexico 87103-1580

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19 ABSTRACT (Continue on reverse if necessary and identify by block number) The North Diversion Structure diverts storm runoff around Albuquerque, New Mexico, to the Rio Grande. Observed flow conditions at the Alameda Outlet Structure, where the flow is transitioned from supercritical to subcritical, have caused concern about the capacity of the as-built channel. A 1:40-scale model was used to determine the flow conditions approaching and through the Alameda Outlet Structure. Included in the model were approximately 1,500 ft of trapezoidal channel, the vehicle access ramp cut in the side of the trapezoidal channel, the trapezoidal to rectangular transition, the super-elevated curve, Camino Arrovo Inlet, the flaring Alameda Outlet Structure with the rail-road bridge and high-velocity pier, and the outlet channel with the graded riprap protection.			
The design capacity of the North Diversion Structure is 44,000 cfs. Flows in the model overtopped the channel walls for discharges above 30,000 cfs due to standing waves (Continued)			
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19. ABSTRACT (Continued).

that formed at the vehicle access ramp. Removing the vehicle access ramp kept the flow within the channel except on the downstream side of Camino Arroyo Inlet where the flow ran up the wall. A deflector was designed to contain the runup flow within the channel.

An envelope curve of discharge and tailwater elevation at the railroad bridge that defined the conditions dangerous to the bridge was developed. Tailwater rating curves were developed and compared with the danger zones. These curves passed through the danger zone with the as-built structure. Diagonal sills 1 ft high were designed that minimized the danger to the railroad bridge. It was determined that improving the exit channel and lowering the tailwater elevation would provide additional safety.

Scour conditions in the outlet channel were identified. The riprap protection for the channel invert was stable with discharges up to 28,000 cfs.

Flow in Camino Arroyo Inlet overtopped the converging walls in the drop inlet for flows above 2,700 cfs.

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PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, US Army, on 28 October 1983 at the request of the US Army Engineer District, Albuquerque (SWA). The studies were conducted by personnel of the Hydraulics Laboratory (HL), US Army Engineer Waterways Experiment Station (WES), during the period November 1983 to February 1986. All studies were conducted under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division. Tests were conducted by Messrs. C. H. Tate, Jr., J. Cessna, L. East, and N. Ford under the supervision of Mr. G. A. Pickering, former Chief of the Locks and Conduits Branch, and J. F. George, Acting Chief of the Locks and Conduits Branch. This report was prepared by Mr. Tate and edited by Mrs. Marsha Gay, Information Products Division.

During the course of the investigation, LTC David E. Peixotto, District Engineer, and Messrs. Jasper Coombes, Elias Quintana, John D'Antonio, Paul Mann, and William Trujillo of SWA, Mr. Dave Brown of the Southwestern Division, and Mr. Larry Blair of the Albuquerque Metropolitan Arroyo Flood Control Authority visited WES to discuss model results and correlate these results with concurrent design work.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres

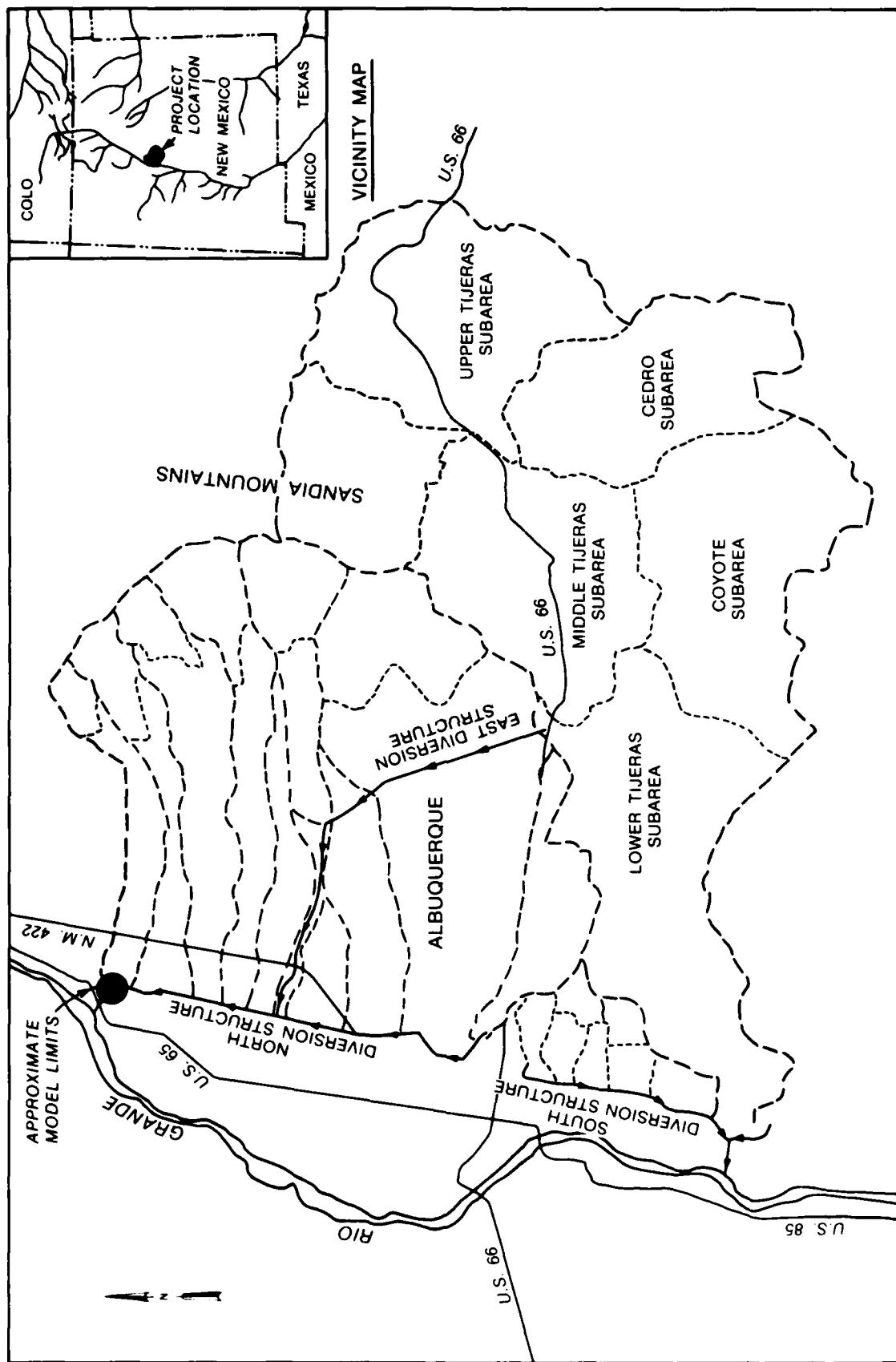


Figure 1. Location map

NORTH DIVERSION STRUCTURE, ALBUQUERQUE, NEW MEXICO

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The North Diversion Structure, north of Albuquerque, New Mexico (Figure 1), intercepts runoff from the arroyos that drain the mesa and western slopes of the Sandia Mountains east of the project. Flow from the arroyos is diverted north around the city and into the Rio Grande. Flow in the diversion structure is supercritical until it passes through the Alameda Outlet Structure and the outlet channel where the flow becomes subcritical prior to entering the Rio Grande. The supercritical portion of the North Diversion Structure is a concrete-lined channel of various cross sections, and the outlet channel downstream of the Alameda Outlet Structure is a trapezoidal channel of natural material with some riprap protection.

2. The North Diversion Structure was designed to convey 44,000 cfs* at the Alameda Outlet Structure with various inflows from each arroyo. Camino Arroyo, which is included in the model study, has a design discharge of 4,500 cfs but contributes 1,600 cfs at the peak discharge of 42,400 cfs in the main channel for the design hydrograph (Figure 2).

3. Within the model limits, the North Diversion Structure approaches the Alameda Outlet Structure as a concrete trapezoidal channel with a 25-ft base width and 1V:2H side slopes (Figure 3 and Plate 1). This section transitions to a rectangular section 70 ft wide in a straight-line transition 450 ft long. Immediately upstream of the transition, a vehicle access ramp was added to the channel after the initial construction was completed. The access ramp involves a 12-ft offset in the right side slope. Downstream of the transition, the channel curves to the left through approximately a 70-deg spiral curve with superelevation. In the upstream portion of the curve, the Camino Arroyo Inlet enters the main channel through an opening in the main

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

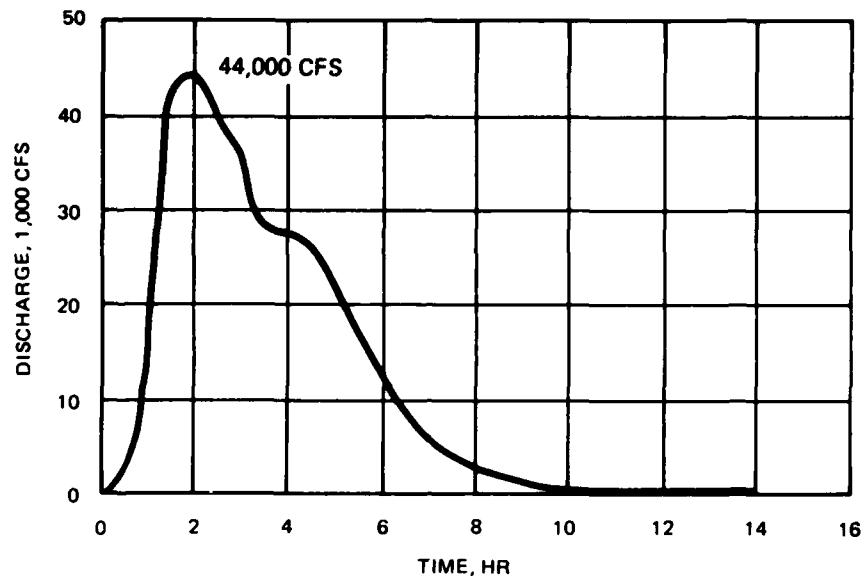


Figure 2. Design hydrograph at the Alameda Outlet Structure

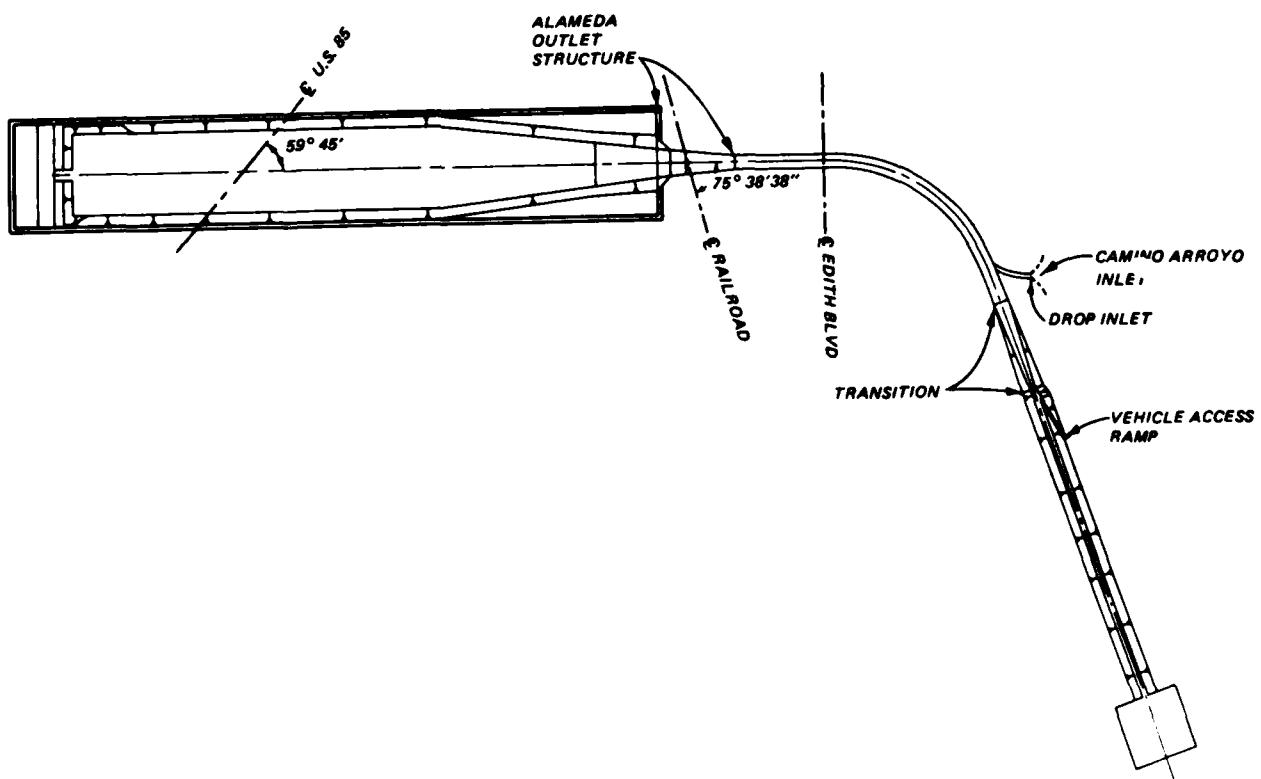


Figure 3. North Diversion Structure, 1:40-scale model

channel right sidewall that is offset above the main channel floor. A 348.04-ft-long straight section downstream of the curve is crossed by Edith Boulevard. The channel then flares as it enters the Alameda Outlet Structure and passes under the Atchison, Topeka and Santa Fe (AT&SF) Railroad bridge. After passing under the railroad bridge, the concrete-lined channel terminates at the low portion of the system (el 5,000.0*) with three rows of baffle blocks. Immediately downstream of the baffle blocks the exit channel is protected with grouted riprap for 317 ft. An additional 520 ft of varying sizes of riprap protects the exit channel invert. The 400-ft-wide exit channel is contained within riprap-protected levees that tie into the river levees. US 85 crosses the exit channel as shown in Figure 3. Downstream of the river levees the exit channel has been cleared of large vegetation, but only a 50-ft-wide exit channel has been excavated to the Rio Grande. The overbank area is 2 to 3 ft above the exit channel invert.

Purpose of Model Investigation

4. Observed flow conditions in the North Diversion Structure and specifically in the Alameda Outlet Structure have raised concerns about the capacity of the channel at the AT&SF Railroad bridge (Appendices A and B). Additionally, flow conditions at the vehicle access ramp have been closer to the top of the channel side slopes than anticipated. Accordingly, the model study was conducted to determine the discharge capacity of the North Diversion Structure and identify any adverse flow conditions. If the study showed that channel discharge capacity was less than designed and if adverse flow conditions existed, modifications were to be designed and tested to mitigate these problems.

* All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

PART II: THE MODEL

Description

5. The 1:40-scale model (Plate 1) reproduced 1,500 ft of trapezoidal channel upstream of the vehicle access ramp, the vehicle access ramp, the superelevated, spiral curve with the Camino Arroyo Inlet to its drop inlet (Photo 1), the Alameda Outlet Structure with the AT&SF Railroad bridge, and the outlet channel to the river levees with the US 85 bridge piers (Photos 2 and 3). The model walls were constructed higher than the prototype walls to prevent spillage in the model. The lines on the walls, shown in Photo 4, approximately represent the top of the prototype walls. Plastic-coated plywood was used to construct the concrete channel with concrete used to install the superelevated portions of the invert. Acrylic plastic was used to construct the railroad bridge pier and the baffle blocks located immediately downstream of the railroad bridge. The exit channel was constructed in a moveable bed form and as a fixed bed. Sand and scaled rock were used to construct the moveable bed that was cement stabilized to form the fixed bed. Modifications to the model were constructed of wood, plastic-coated plywood, and acrylic plastic as required. Galvanized sheet metal was used to construct the railroad bridge and the I beams under the bridge.

6. The coefficient of roughness of the model surface of the channel had previously been determined to be approximately 0.009 (Manning's n). Basing similitude on the Froudian relation, this n value would be equivalent to a prototype n of 0.017. The n value used in the design and analysis of the prototype channel was 0.013; therefore, a supplementary slope was added to the model to correct for the difference in the n values of the model and prototype.

7. Flow to this model was supplied through a circulating system. Discharges were measured with differential pressure manometers and controlled with a manual gate valve. Hydrographs were reproduced with stepped operation to approximate the hydrograph flows and duration.

8. Water-surface elevations in the outlet channel were controlled with a broad-crested weir at the downstream end of the model. The elevation of the broad-crested weir was modified to reproduce various outlet channel

configurations. An adjustable tailgate was used to create artificially high tailwater elevations when necessary.

9. Velocities were measured in the model with pitot-static tubes and with propeller meters with a minimum measurable velocity of approximately 0.4 fps prototype. Point gages were used to measure water-surface elevations throughout the model. Flow conditions were observed for all designs tested, with the original designs and the potentially usable designs and associated flow conditions being recorded photographically.

Scale Relations

10. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. These general relations were used for the transference of model data to prototype equivalents:

<u>Characteristic</u>	<u>Dimension*</u>	<u>Model:Prototype</u>
Length	L_r	1:40
Area	$A_r = L_r^2$	1:1,600
Velocity	$V_r = L_r^{1/2}$	1:6.325
Discharge	$Q_r = L_r^{5/2}$	1:10,119
Volume	$V_r = L_r^3$	1:64,000
Weight	$W_r = L_r^3$	1:64,000
Time	$T_r = L_r^{1/2}$	1:6.325
Roughness coefficient	$N_r = L_r^{1/6}$	1:1.849

* Dimensions are in terms of length

Model measurements of discharge, water-surface elevations, and velocities can be transferred quantitatively to prototype equivalents by means of the scale relations. Experimental data also indicate that the model-to-prototype scale ratio is valid for scaling stone in the sizes used in this investigation. Evidences of sand scour are considered only qualitatively reliable, since it is not yet possible to reproduce quantitatively in the model the resistance to erosion of fine-grained, prototype bed material.

PART III: TESTS AND RESULTS

11. Initial tests of the model indicated that several flow problems existed with the as-built structure. A large oblique standing wave formed at the vehicle access ramp and for the desgn flow overtopped the channel walls, as shown in Photo 4. The standing wave reflected downstream and overtopped the channel walls in several other places. Camino Arroyo Inlet geometry amplified the reflected wave and caused the flow to overtop the channel walls at the downstream inlet wall. For flows greater than 30,000 cfs, the reflected waves overtopped the channel walls through the remainder of the curve and at points downstream of the curve (Photo 5). An oblique jump formed at the railroad bridge and created unacceptable flow conditions under the bridge between flows of 10,000 and 15,000 cfs (Photo 6). Due to the effects of the curve upstream of the railroad bridge, the flow velocities were skewed to the right side of the channel, causing the oblique jump and flow circulation immediately downstream of the jump for intermediate flows. At the downstream edge of the grouted riprap (sta 45+20.69), riprap failure occurred at 28,000 cfs. For higher flows, general riprap failure occurred for the ungrouted riprap on the right side of the exit channel invert (Photo 7). Significant scour occurred downstream of the riprap at the toe of the right levee (Photos 7 and 8). Additionally, flow overtopped the walls at the base of the Camino Arroyo drop inlet for flows greater than 2,700 cfs and up to the maximum design discharge of 4,500 cfs.

Vehicle Access Ramp

Prototype

12. The model flows (Photo 9) closely matched the observed prototype conditions as determined by Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) personnel. The sudden expansion in the right side slope of the trapezoidal channel formed by the vehicle access ramp caused a standing wave to form for all flows. The standing wave formed at the vehicle access ramp on the right side of the channel and crossed the channel diagonally to the left side where the wave was reflected downstream through the transition section to Camino Arroyo Inlet. At Camino Arroyo Inlet the flow formed another standing wave due to the gap in the right side of the channel. The

reflected wave from the vehicle access ramp intersected the right wall of the channel at Camino Arroyo Inlet and the two waves combined at that point. Flow overtopped the walls by up to 10 ft at this point. The combined wave reflected through the curve and overtopped the channel walls in several places as shown in Plate 2. Overtopping of the walls started at approximately 30,000 cfs.

Type 2 channel

13. Removing the vehicle access ramp and restoring the trapezoidal shape of the channel down to the transition eliminated the standing wave at that location for all flows. Flow conditions for this design are shown in Photos 10 and 11. When this standing wave was removed, the flow remained within the channel except at the intersection with Camino Arroyo Inlet where the flow conditions were significantly improved (Photo 12). Water-surface profiles for the type 2 channel are shown in Plate 3.

Type 3 channel

14. AMAFCA expressed a need to retain vehicle access at this location. To minimize the expansion effects of the vehicle access ramp, the side slope uphill from the ramp was replaced with a vertical wall up to the projected trapezoidal channel side slope. The side slope was then continued, resulting in a "notch" in the side of the channel. The standing wave was greatly reduced with this ramp; however, flow overtopped the channel walls in the curve by up to 2 ft and by considerably more at Camino Arroyo Inlet. This design was not considered acceptable and no additional tests were conducted with it.

Camino Arroyo Inlet

15. As shown in Plate 2, the flow at Camino Arroyo Inlet overtopped the channel walls at the junction with the downstream wall of Camino Arroyo Inlet. This overtopping was due to the standing wave caused by the vehicle access ramp and by the flow conditions resulting from flow falling into the gap in the main channel wall formed by Camino Arroyo Inlet. This flow impacted and ran up the downstream wall. The sudden expansion in the channel at the gap and the flow disturbance caused by the gap set up an additional standing wave that combined with the wave from the access ramp and contributed to the water-surface elevation at the Camino Arroyo Inlet. The combined effects caused the flow to overtop the channel walls by up to 10 ft.

16. Gradual offsets upstream of Camino Arroyo Inlet were tested to keep the flow from falling into the gap in the main channel wall. These offsets produced severe flow disturbances and reduced the capacity of the channel such that flow conditions were worse than with the as-built design.

17. Based on discussions with US Army Engineer District, Albuquerque, cantilevered plates were tested to cap the runup at the top of the channel walls. For the as-built condition, the type 1 deflector shown in Plate 4 was developed to contain the runup and the reflected standing wave from the access ramp. This design required the cantilevered plate to angle up 20 deg from horizontal to contain the reflected wave. The required size of this plate probably precludes construction. For the type 2 channel where the access ramp is removed, the design shown in Plate 5 was developed. This design is considerably smaller than the type 1 deflector and is essentially a horizontal lid. Construction difficulties are evident in the type 2A deflector. Based on reduced runup for the type 2 channel, the type 2B deflector was developed as shown in Plate 6 to contain the runup within the channel rather than to put a lid on the runup. This design uses a 45-deg wedge, 2 ft on the normal sides, to deflect the flow away from the wall and back to the channel. The top of the type 2B deflector is even with the top of the channel walls.

Railroad Bridge

18. Flow velocities approaching the railroad bridge were skewed with higher velocities toward the right side of the channel as a result of the curve upstream of the bridge. Isovels at various stations are shown in Plates 7 and 8 for flows of 11,000 cfs and 44,000 cfs, respectively. An oblique jump was formed near the railroad bridge for flows below 20,000 cfs with the as-built design (Photo 6). Higher discharges caused the jump to sweep out past the baffle blocks. Under these conditions, a jump did not form (Photo 13). The location and height of the oblique jump were extremely sensitive to the tailwater elevation downstream of the railroad bridge. A bridge danger zone envelope was developed that combined the effects of discharge and tailwater elevations, as shown in Plate 9. The danger zone was defined as any combination of flow and tailwater elevation that caused flow to impinge consistently on the bottom of the railroad bridge. This was a subjective determination, and every effort was made to be conservative in the sense that

marginally dangerous conditions were included in the danger zone envelope. A dependable tailwater rating curve did not exist for the prototype for comparison with the bridge danger zone envelope. The model was used to develop the tailwater rating curve for the as-built conditions by approximating the controlling conditions downstream from the excavated exit channel. As shown in Plate 9, the resulting rating curve passes through the bridge danger zone envelope for the as-built project with the existing exit channel. Improving the exit channel by excavating the full width of the channel to the Rio Grande would slightly lower the tailwater rating curve as shown in Plate 9 (improved exit channel). However, this curve also passes through the bridge danger zone envelope.

19. Evaluation of the flow conditions at the railroad bridge indicated that the best flow conditions that could be achieved would occur with a uniform hydraulic jump at the railroad bridge. To achieve this flow condition, the velocity distribution at the railroad bridge needed to be modified. A literature search into methods to modify supercritical flow in curves produced one method that had potential use in this situation. Knapp and Ippen* developed the use of low diagonal sills in curves to modify the standing wave pattern, resulting in lower maximum water-surface elevations. This design was tested and did result in lowering the maximum wave heights. Unfortunately, the average water-surface elevation was increased to the point that the flow overtopped the channel walls throughout the curve and the velocity distribution exiting the curve was not significantly changed.

20. Other modifications were considered for the curve upstream of the railroad bridge. All of these modifications appeared to be very costly to install in the prototype and were highly dependent on discharge for acceptable flow conditions. Modifications to change the flow conditions downstream of the curve were then considered based on the concept that the uniform jump was necessary only in the 10,000- to 15,000-cfs flow range to provide the lowest possible jump height as the jump moved under the bridge. For all other flows the resulting conditions needed to be acceptable but not necessarily perfect.

* Robert T. Knapp and Arthur T. Ippen. 1938 (Sep). "Curvilinear Flow of Liquids with Free Surfaces at Velocities Above That of Wave Propagation," Proceedings of the Fifth International Congress for Applied Mechanics, Harvard University and the Massachusetts Institute of Technology, Cambridge, Mass., pp. 531-536.

21. Several arrangements and sizes of baffle blocks were tested in the flaring section upstream of the railroad bridge (types 2-10). Some nonsymmetrical arrangements produced acceptable jump conditions at the bridge, but produced unacceptable flow conditions for higher flows. Based on a combination of the concepts used in the diagonal sills developed by Knapp and Ippen* and the flow requirements at the railroad bridge, a diagonal sill was designed and installed upstream of the bridge (type 11). This 1-ft-high sill produced acceptable flow conditions across the channel under the bridge except at the right wall where flow curled away from the wall. A short section of opposing diagonal sill was installed downstream of the main sill to form the type 12 sill design (Photo 14). The location of the sills in the type 12 sill design is shown in Plate 10 along with the minimum lengths for acceptable performance. This design had minimal impact on flow conditions once the jump was pushed downstream of the railroad bridge (Photo 15). The bridge danger zone envelope (defined in paragraph 18) for the type 12 design was developed similar to that for the as-built design and is compared in Plate 9 with both the as-built exit channel and the improved exit channel tailwater rating curves. For the as-built exit channel, the tailwater rating curve intersects the bridge danger zone at one point at the lower edge of the zone. The improved exit channel tailwater rating curve does not intersect the bridge danger zone for the type 12 sill design. The lower tailwater allows the jump to pass under the bridge at a lower flow, as shown in Photo 16 compared with Photo 14.

Riprap

22. The as-built riprap protection is shown in Plate 11. The upstream portion of the riprap is grouted with concrete between sta 48+37.26 and 45+20.69. Riprap in the model was also grouted with a mortar mixture; however, the model does not simulate the strength of the grouted riprap. For flows up to 28,000 cfs, the riprap was stable in the model. Higher flows (Photo 17) resulted in the nongrouted riprap failing on the right side of the exit channel beginning at the downstream edge of the grouted riprap (Photo 7). Significant scour also occurred at the downstream edge of the riprap in the channel invert at the base of the right bank (Photo 8). Riprap failure and

* Knapp and Ippen, op. cit.

scour were more pronounced for the improved exit channel (Photo 18).

Vehicle Access

23. Several modifications were considered to provide vehicle access to the upstream side of the baffle blocks located immediately downstream of the railroad bridge. Total removal of the baffle blocks caused no significant change in the performance of the Alameda Outlet Structure; however, velocities were higher on the riprap immediately downstream of the concrete invert. Removal of two baffle blocks adjacent to the walls in each row increased the velocities on the grouted riprap from 25 fps to a maximum of approximately 45 fps with the design flow. Removal of center baffle blocks (one from the outside rows and two from the middle row) resulted in a maximum velocity on the riprap of approximately 31 fps due to the shadow effect of the railroad bridge pier.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

24. Tests to ascertain the capacity of the North Diversion Structure to convey the design flow conditions indicated that the structure with certain modifications would perform satisfactorily. Installation of the type 12 sill would minimize the risk to the AT&SF Railroad bridge without any additional change to the as-built project. Excavating the exit channel full width to the Rio Grande would improve the conditions at the railroad bridge.

25. Wave action caused by the vehicle access ramp overtopped the channel walls in many locations for flows above 30,000 cfs. The safe solution to this problem is to remove the vehicle access ramp and restore the trapezoidal channel between sta 75+35 and 72+50. With the vehicle access ramp removed, the type 2B deflector should be installed at Camino Arroyo Inlet to contain the flow within the channel at this location.

26. The nongROUTED as-built riprap failed in the model for flows above 28,000 cfs. AMAFCA personnel were willing to accept some damage to the channel invert for flows of that magnitude due to the infrequency of such flows and the costs associated with providing additional scour protection. Additionally, scour to the channel invert should not threaten the integrity of the structure. Some consideration should be given to providing additional scour protection to the toe of the right levee between sta 45+20.69 and 36+00 due to the scour potential exhibited in the model.

27. AMAFCA emphasized its desire for local vehicle access to the Alameda Outlet Structure to facilitate the removal of sediment in this area. Removal of the vehicle access ramp without a local alternative form of access would force several additional miles of transport costs for AMAFCA. An alternative to the vehicle access ramp and the removal of several baffle blocks would be the construction of a dirt ramp over the baffle blocks. Such a ramp could be left in place and would probably wash out during significant flow events. The costs of rebuilding the ramp with local materials should be minimal.

28. The drop inlet for Camino Arroyo Inlet will not contain the design flow of 4,500 cfs. Maximum flow before the walls are overtopped is 2,700 cfs. Proposed plans to divert 2,000 cfs from Camino Arroyo Inlet to La Cueva Inlet should correct this problem by reducing the maximum flow to 2,500 cfs or less.



Photo 1. Trapezoidal channel, vehicle access ramp, transition, curve,
and Camino Arroyo Inlet



Photo 2. Alameda Outlet Structure

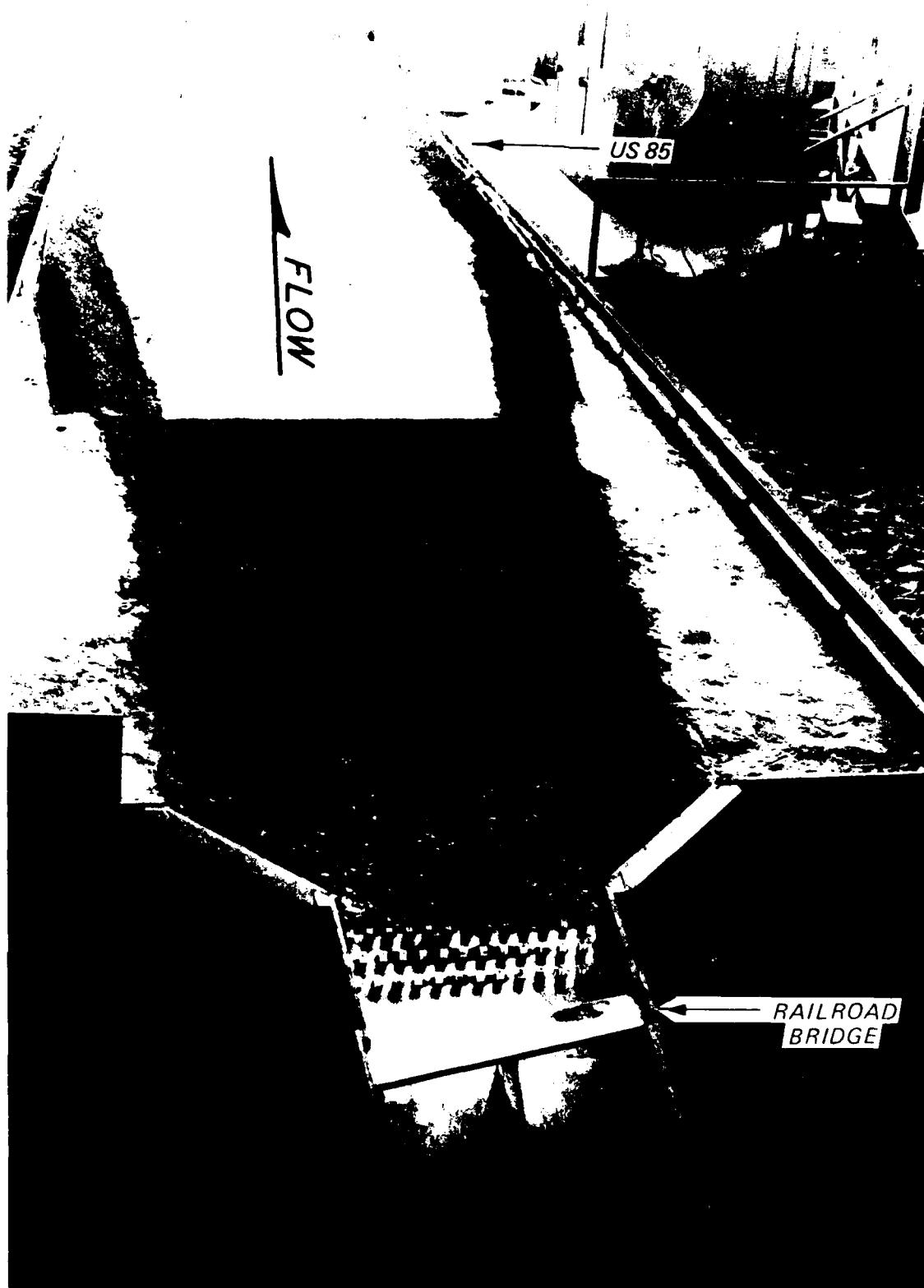


Photo 3. Alameda Outlet Structure and outlet channel, original design



Photo 4. Vehicle access ramp, original design, North Diversion Channel
discharge 42,400 cfs, Camino Arroyo Inlet discharge 1,600 cfs



Photo 5. Camino Arroyo Inlet and North Diversion Channel junction, design discharge



Photo 6. Flow of 11,000 cfs at the railroad bridge with the original design, tailwater el 5,031.9

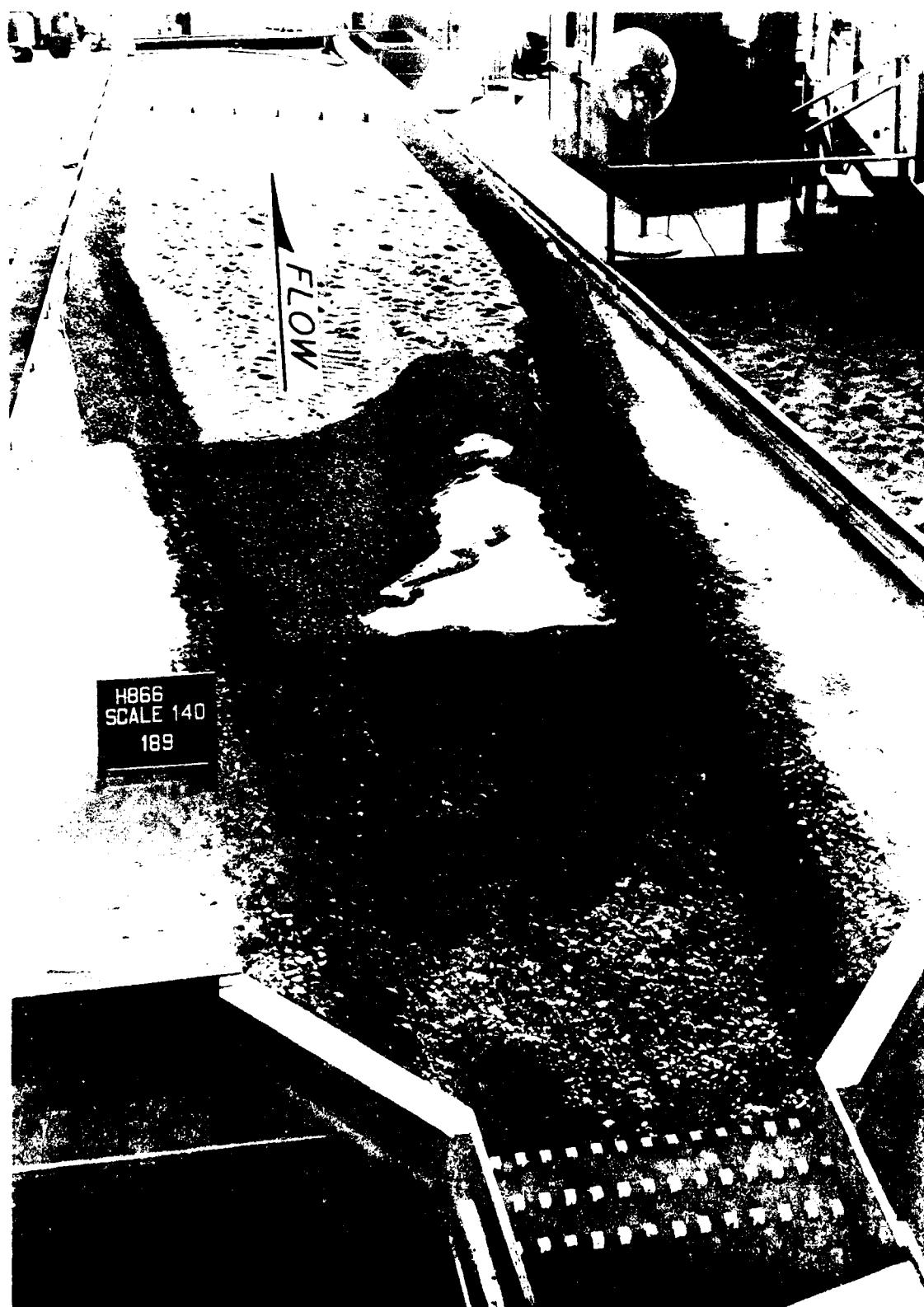


Photo 7. Outlet channel scour after design hydrograph, original design



Photo 8. Outlet channel scour at the downstream edge of the riprap, original design



Photo 9. Vehicle access ramp, original design, North Diversion
Channel discharge 11,000 cfs



Photo 10. Vehicle access ramp removed, type 2 design, North Diversion Channel discharge 11,000 cfs



Photo 11. Vehicle access ramp removed, type 2 design, North
Diversion Channel discharge 42,400 cfs



Photo 12. Camino Arroyo Inlet and North Diversion Channel junction, type 2 vehicle access ramp, design discharge



Photo 13. Design discharge at the railroad bridge, original design



Fig. 1. A bridge pier with the concrete and two steel sills exit the water. The bridge pier is 100% damaged.





Photo 14. Discharge of 12,000 cfs at the railroad bridge with the type 12 sills and the improved exit channel, tailwater el 5,013.5

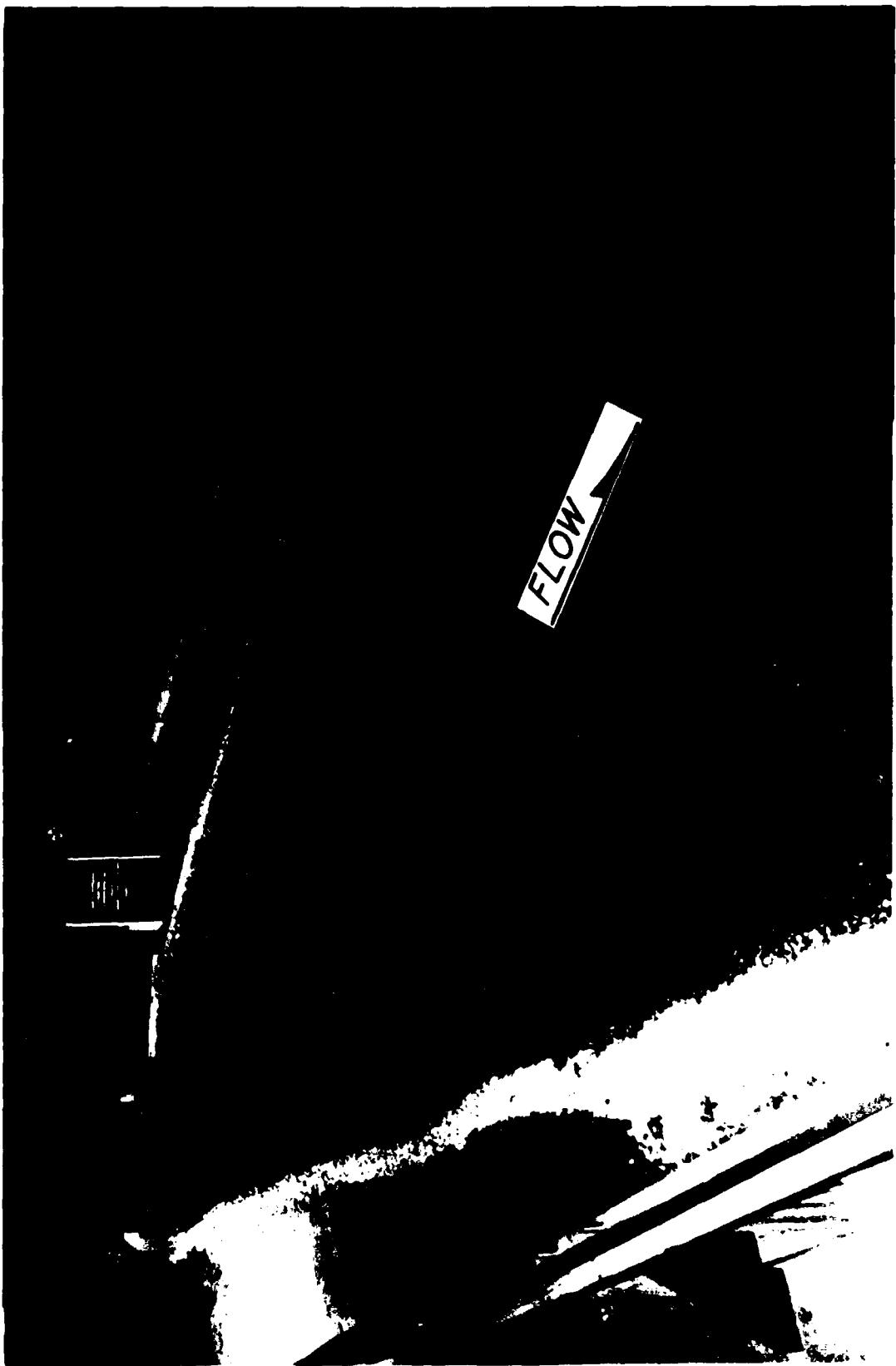


Photo 17. Design flow in the exit channel

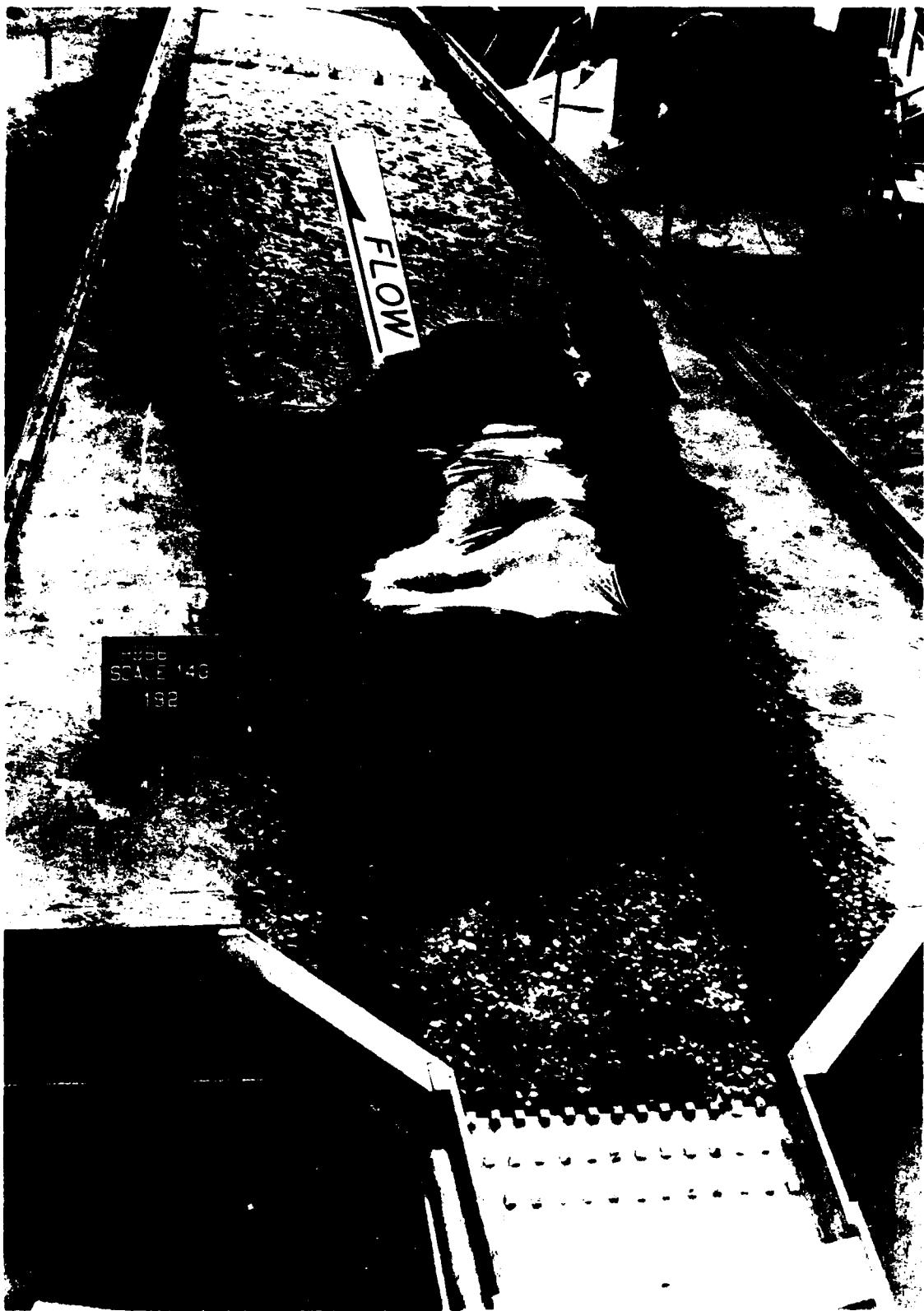


Photo 18. Outlet channel scour after design hydrograph,
improved exit channel

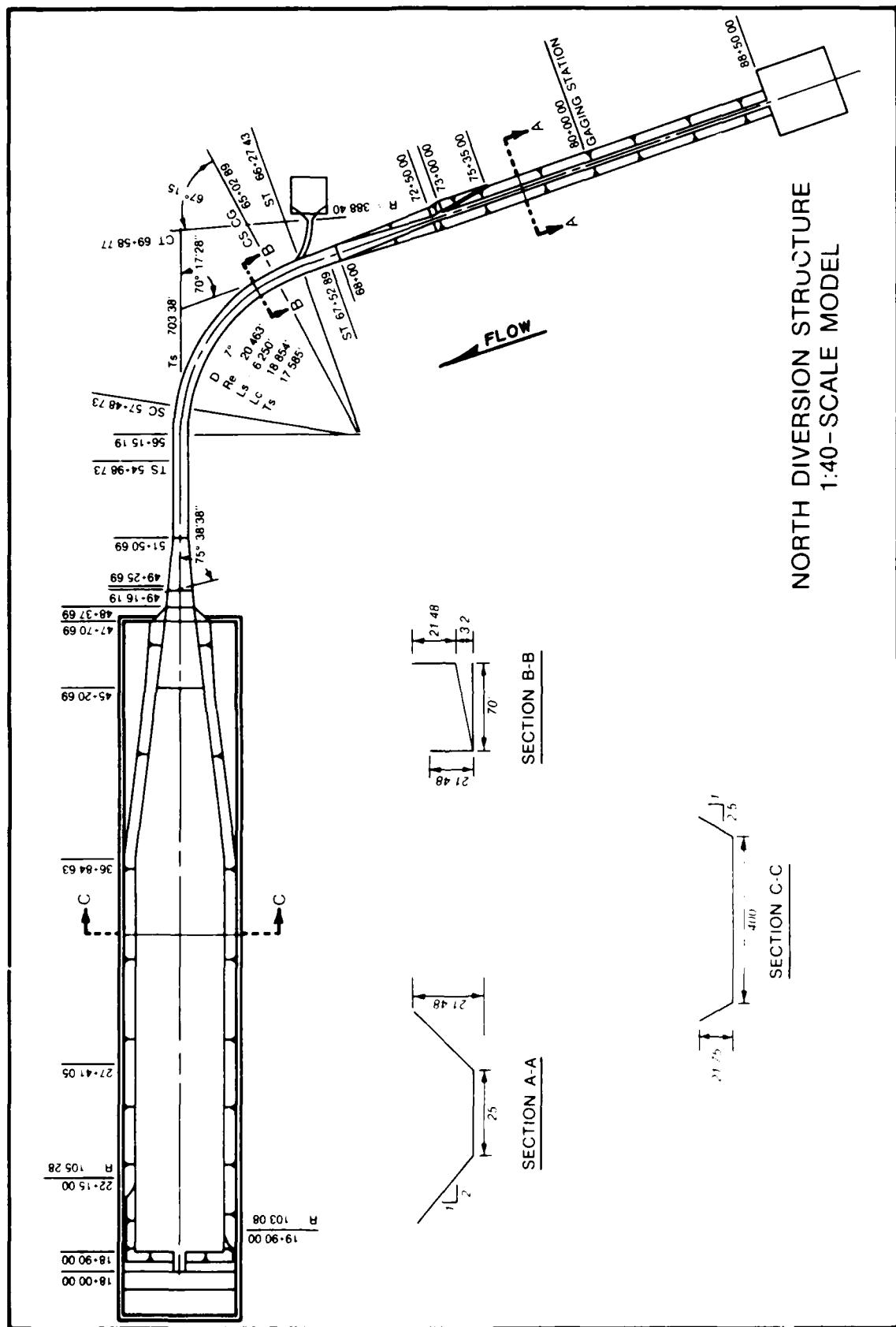


PLATE 1

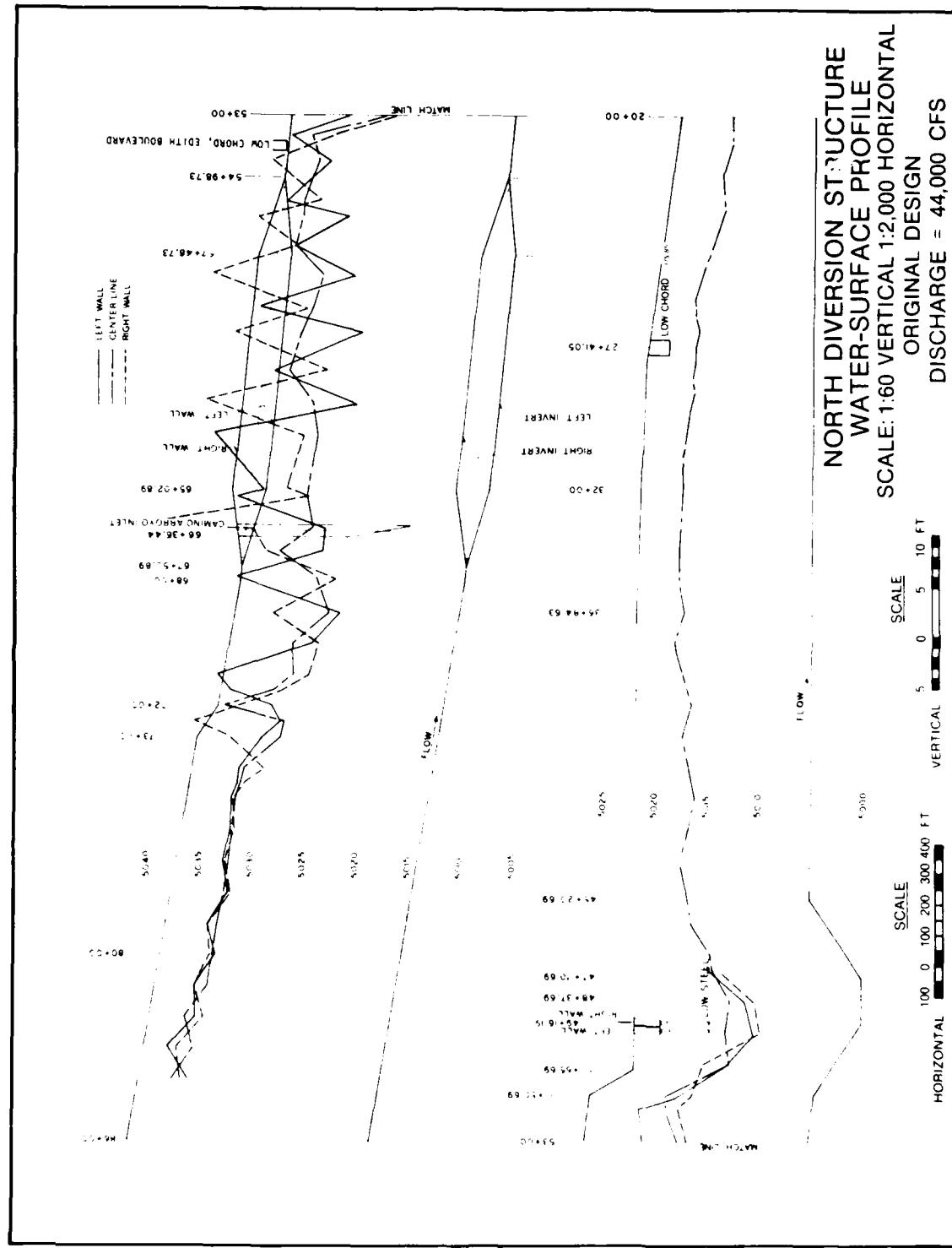


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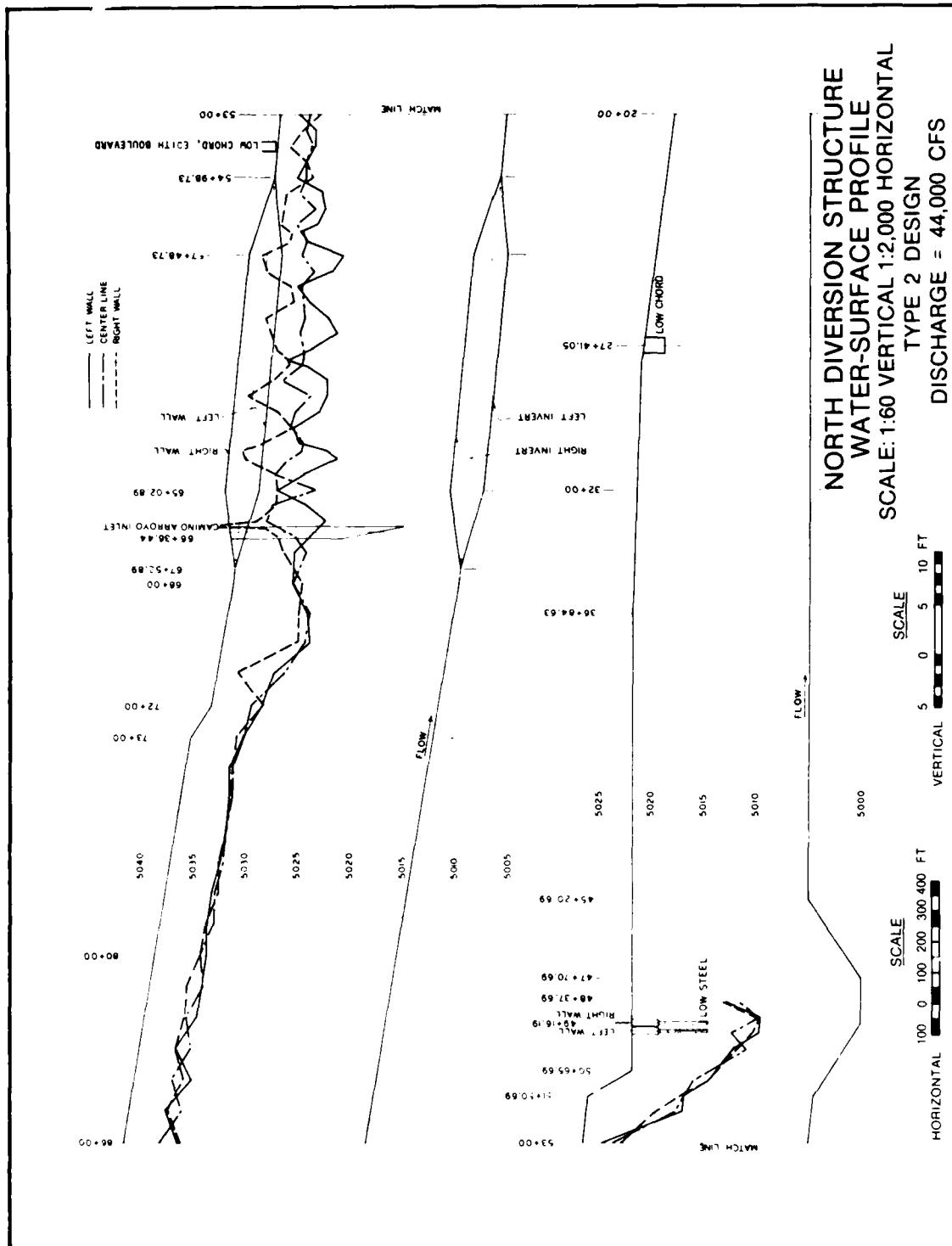


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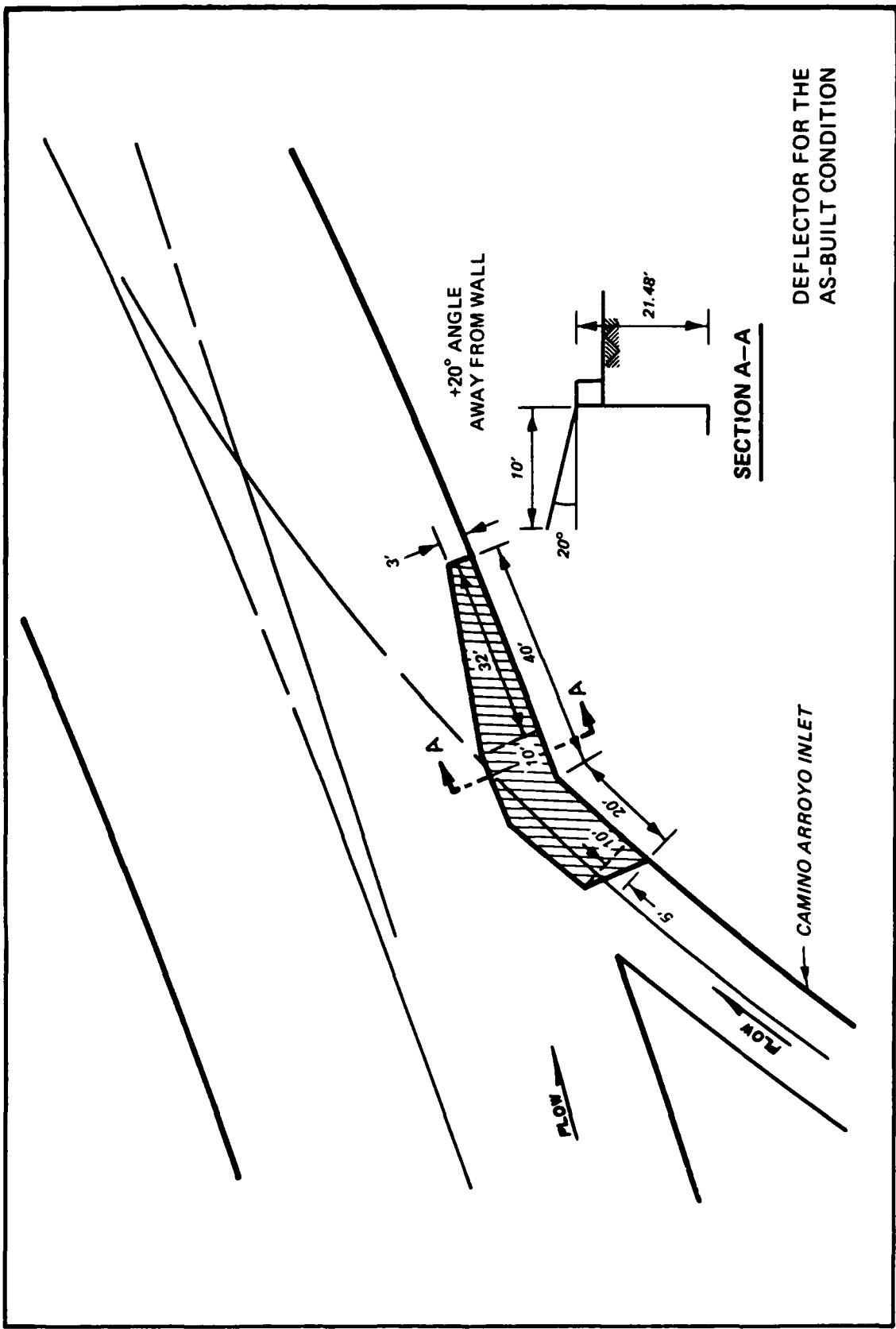
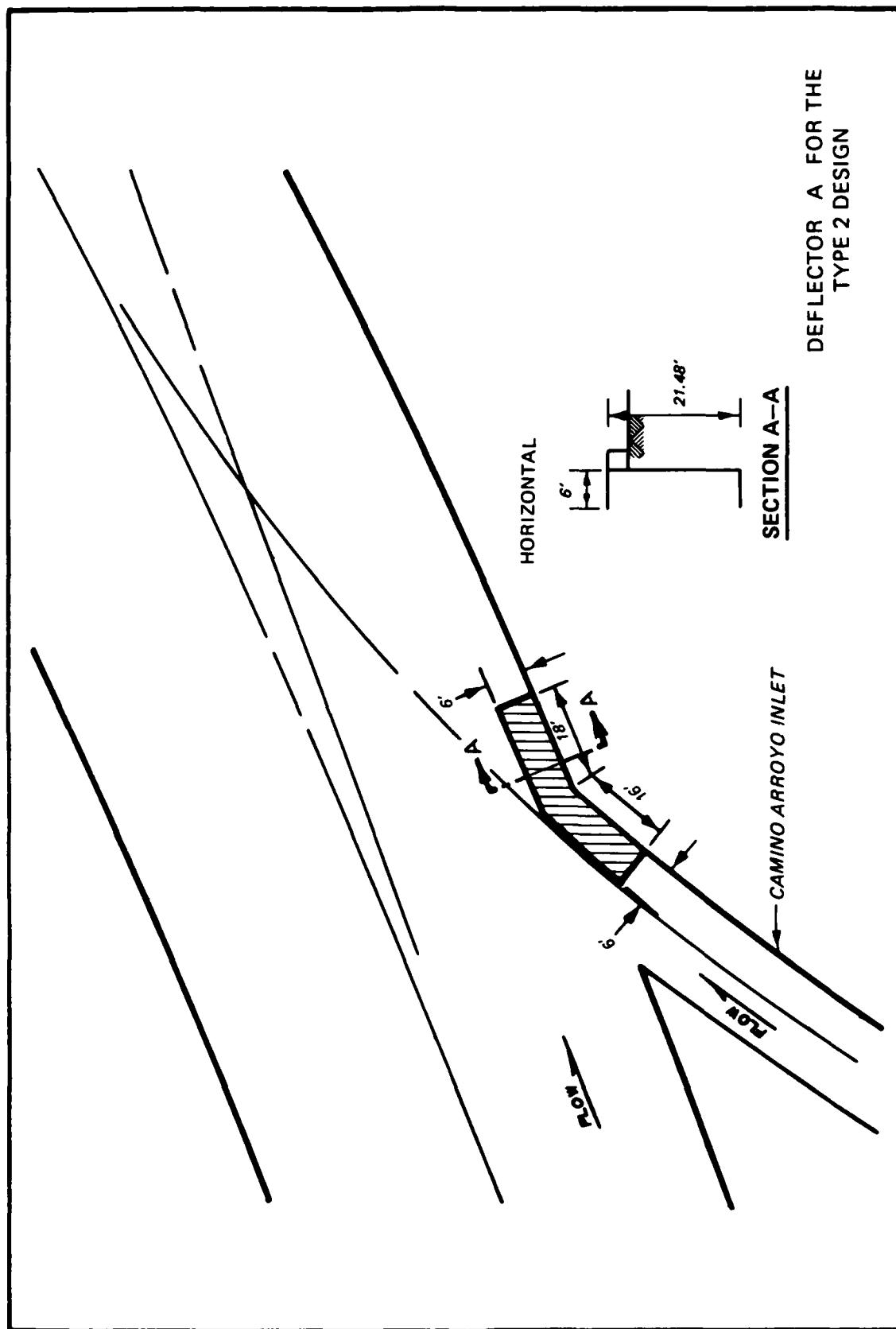
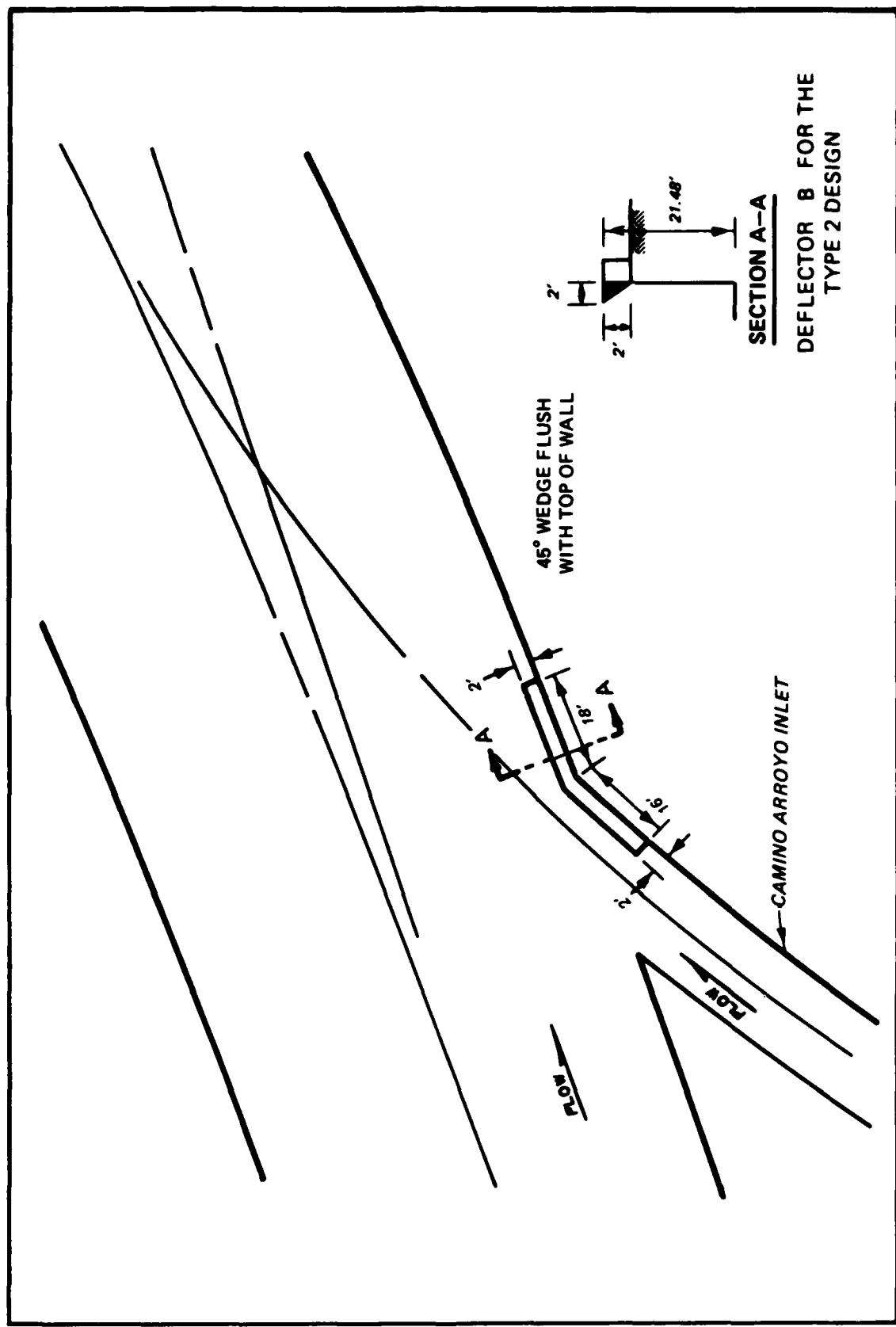


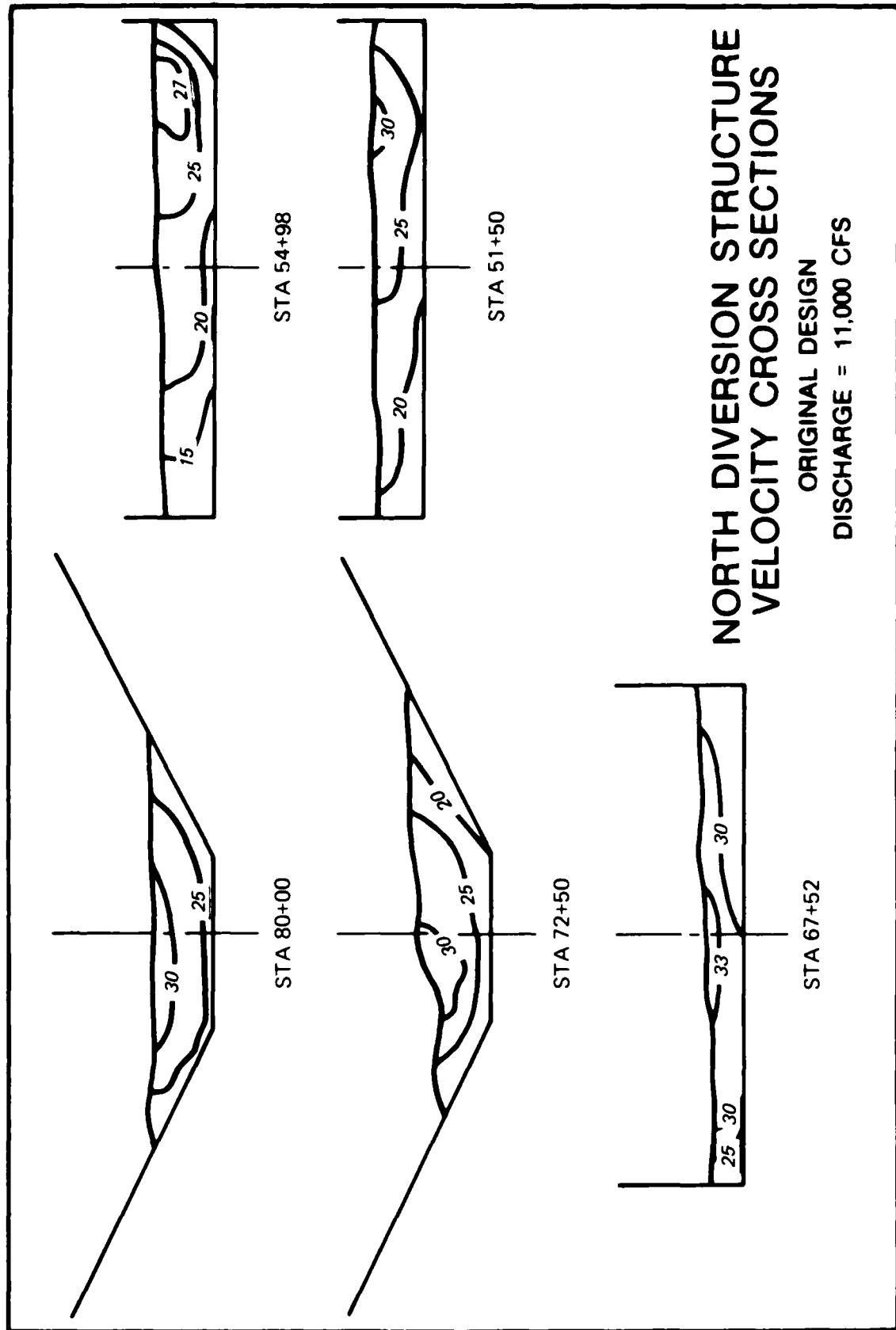
PLATE 4

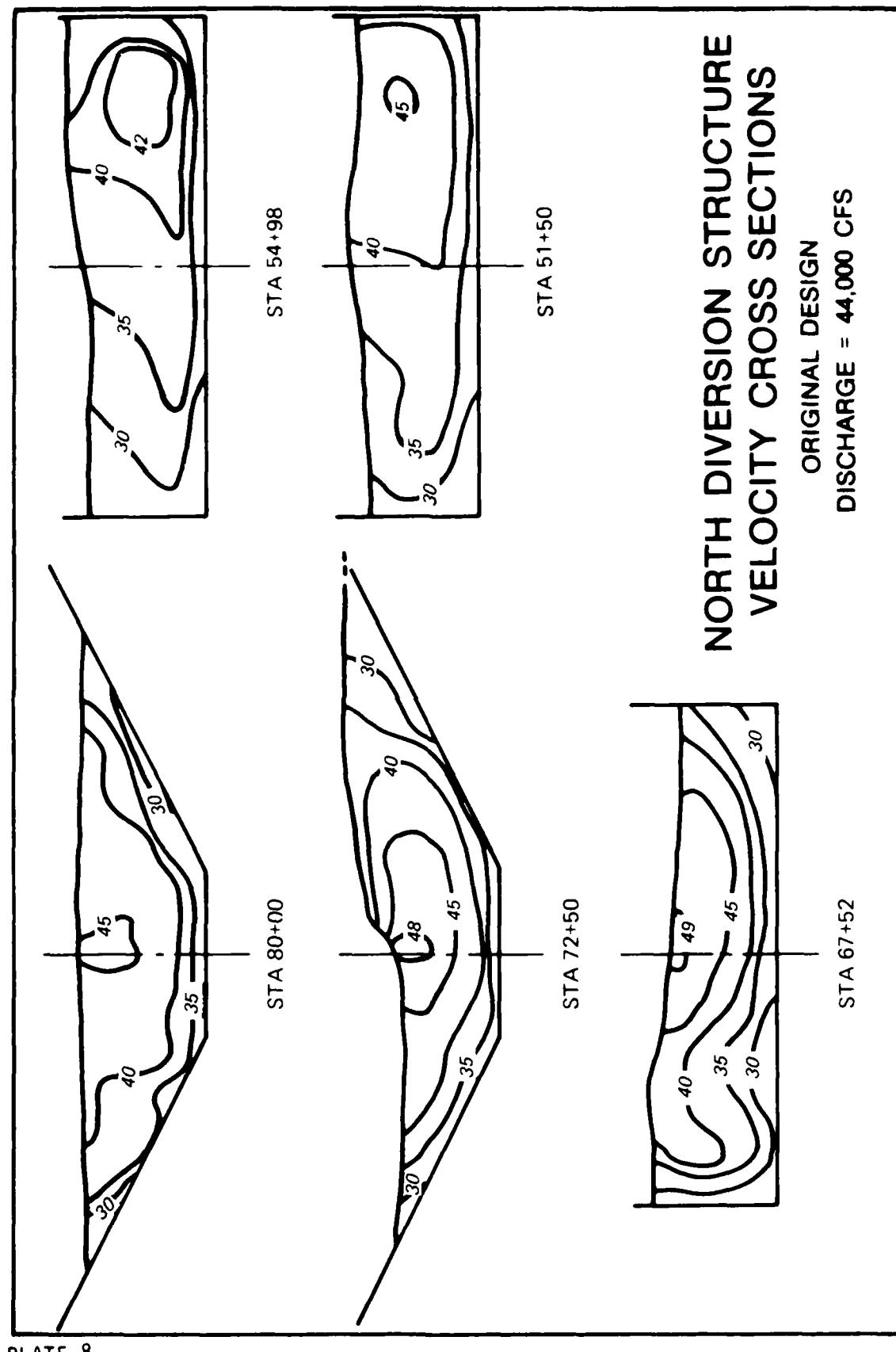




**NORTH DIVERSION STRUCTURE
VELOCITY CROSS SECTIONS**

ORIGINAL DESIGN
DISCHARGE = 11,000 CFS





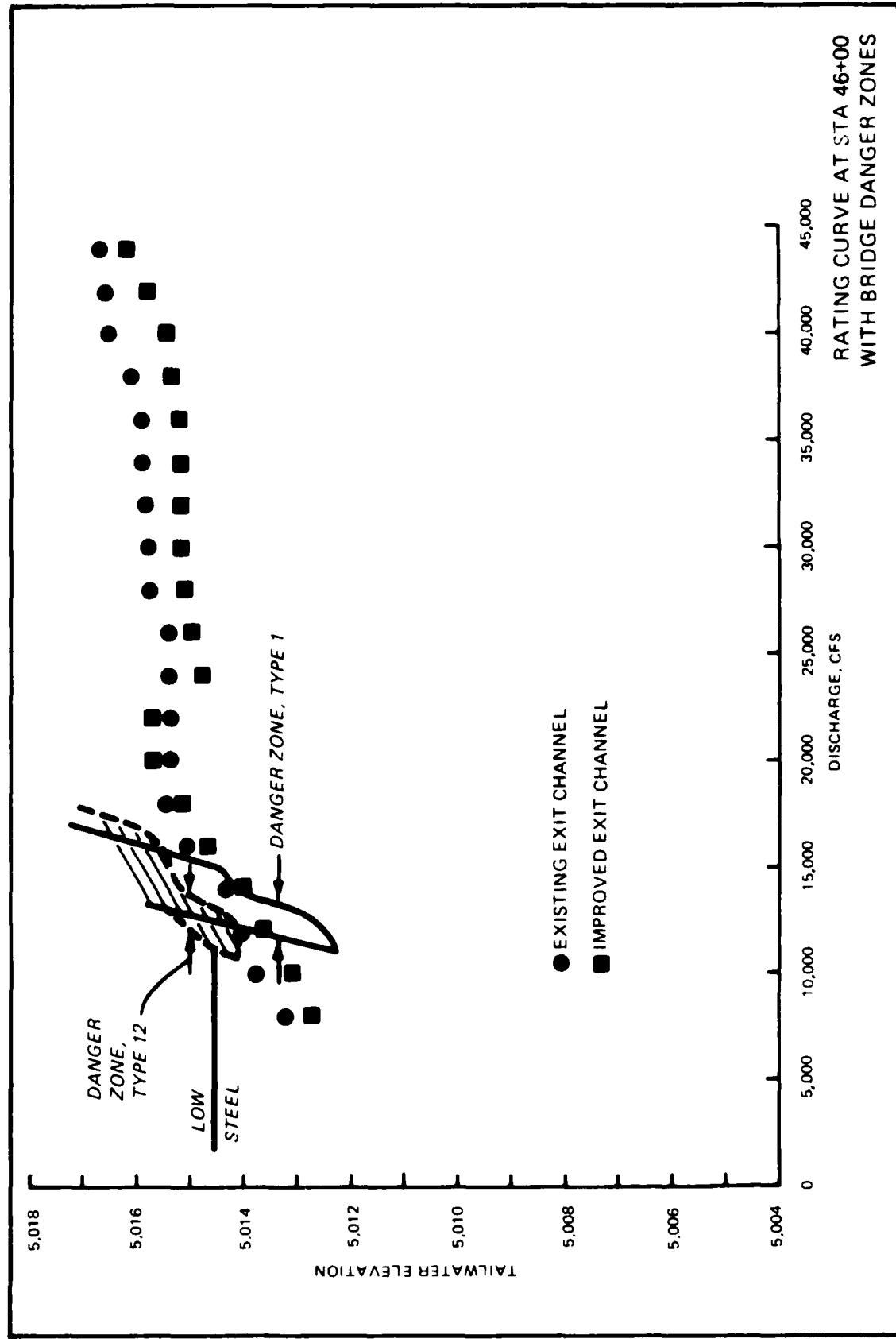


PLATE 9

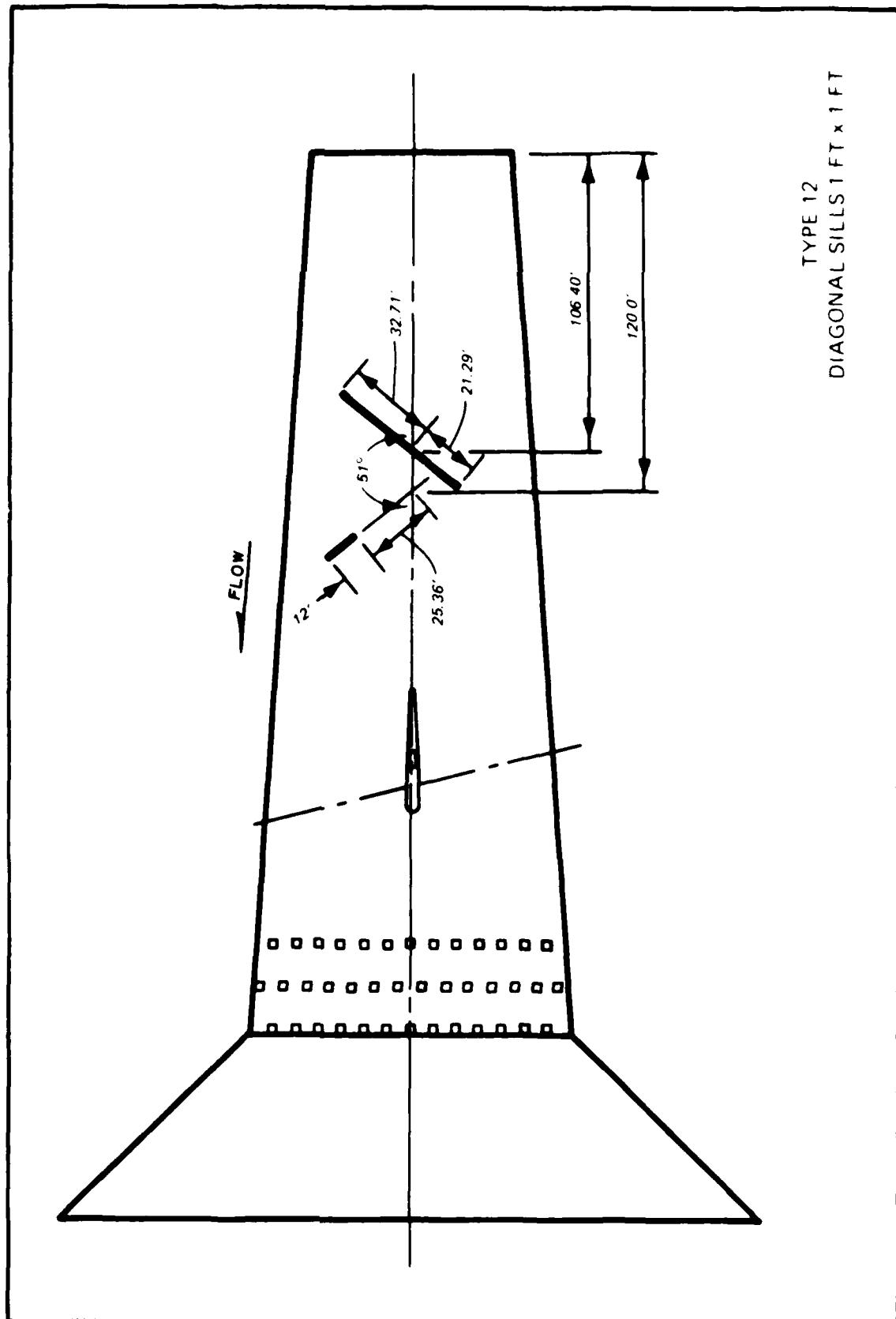
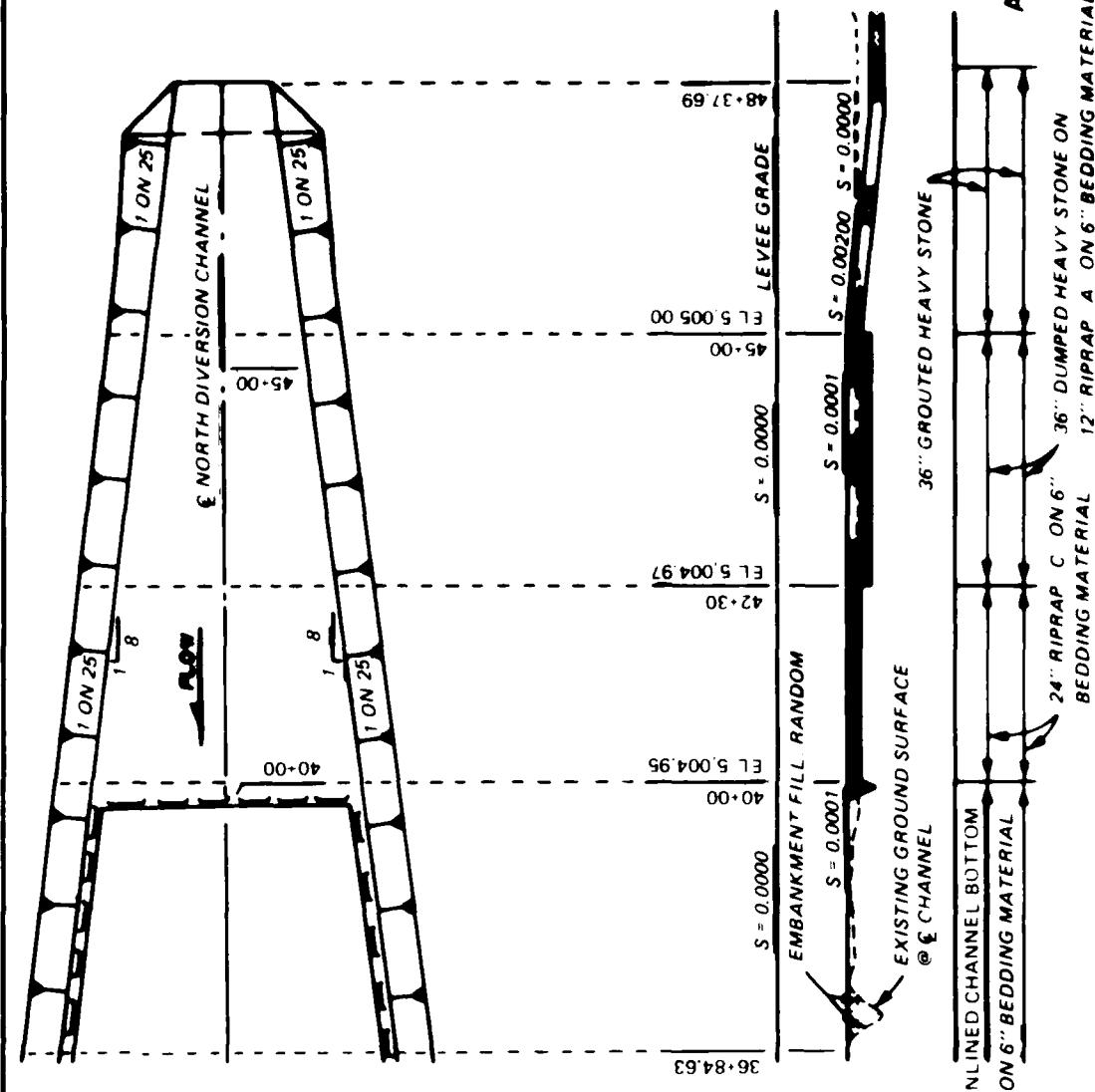


PLATE 10



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PLATE 11

APPENDIX A

MEMORANDUM ON THE ALAMEDA OUTLET STRUCTURE PERFORMANCE DURING FLOOD OF 14 AUGUST 1980

1. The Alameda Outlet Structure.

a. The Alameda Outlet Structure is the northern terminus of the Albuquerque North Diversion Channel. It is shown in Inclosure 2 [Not included here. See Plate 1 of report.] and consists of the following substructures in order of their positioning, moving downstream.

(1) A rectangular supercritical flow transition in which the channel is widened from 70 feet to 100 feet between Sta 51+50.69 and Sta 49+16.19. The centerline of the AT & SF Bridge crosses this transition at Sta 49+25.69.

(2) A stilling basin with baffle blocks from Sta. 49+16.19 to 48+37.69.

(3) A transition from Sta 48+37.69 to 36+84.63. In which the channel width is increased to 400 feet. This section is also the downstream portion of the stilling basin.

(4) A 400 feet wide outfall channel from Sta 36+84.63 to 18+90, downstream from the stilling basin.

(5) A 50 foot wide pilot channel which extends westward from the end of the outfall channel to the Rio Grande.

b. Flows emerging from the North Diversion Channel are in a supercritical state. The function of the Alameda Outlet Structure is to transition these flows to a subcritical state before releasing them into the Rio Grande.

2. Performance of the Alameda Outlet Structure. During the storm of 14 August 1980, Mr. Richard Leonard of AMAFCA and Messrs. John Cunico, Boyd Lare and John Guiney of the Albuquerque District, were witnesses to the performance of the Alameda Outlet Structure. The observations of the witnesses were as follows:

a. Mr. Leonard, who was at the site at approximately 5:30 a.m. near the time when the peak flow of 11,000 cfs¹ was occurring, observed a hydraulic jump upstream of the Santa Fe Railroad Bridge in which "water was splashing against but not quite impinging on the bridge stringer."² In addition, Mr. Leonard observed "there appeared to be eddies in the south part of the channel just downstream from the railroad bridge. Some water may have been flowing upstream under the bridge on the south side." Flow depth was approximately 12 1/2 feet on the sidewall gauge immediately downstream from the bridge.

¹The USGS maintains a continuous gage upstream of the outlet structure.

²The bridge referred to is the AT&SF railroad bridge which crosses over the outlet structure at Sta 49+26.

b. The above mentioned COE personnel were at the site approximately 9:00 a.m. when the discharge was about 2,000 cfs. No hydraulic jump was seen at this time but a definite reverse flow through the south bay of the railroad bridge was observed.

3. Field Trip. On August 27, 1980 Messrs. Elias Quintana and Joe Wexler of the FPM&H Branch visited the Alameda Outlet Structure. The results of the trip are summarized as follows:

a. The maintenance road traverses the subcritical transition and the outfall channel downstream of the railroad bridge in several directions (see Incl 2). The road is higher than the channel invert at all locations and tends to act as a barrier and/or training wall when flowing water is present. The slope of the Alameda Outfall channel is 0.0001 ft/ft which results in a total difference in elevation of only 0.26 feet between stations 45+21 and 18+90. The functioning of any flood control channel will be affected by the presence of obstructions, but because of the flatness of the Alameda outfall, obstructions result in especially severe results as described in the following paragraphs.

(1) The maintenance road crosses the transition at an angle about 45°, approximately 450 downstream from the baffle blocks. The road which is approximately 2.5 feet higher than the channel invert, turns west (parallel to direction of flow) at approximately station 42+00, leaving a 50 ft wide channel between the road and the south levee. At low discharges, the maintenance road diverts flow to the 50 ft channel at the south side of the transition where it can flow unimpeded down to the pilot channel which begins at station 18+90. At higher discharges part of the flow will move down the small side channel but the bulk of the flow must pass over the maintenance road in order to continue downstream. The road builders may have intended for it to be eroded away during high flows, but this did not happen. During the storm of 14 August 1980 the erosive force of the flowing water narrowed the road at several locations, but nowhere was the road breached and for the entire duration of the storm the road functioned as a broad-crested weir. This situation caused increased depths of flow in the area between the maintenance road and the baffle blocks which resulted in the hydraulic jump being formed upstream from the railroad bridge, whereas it should have been occurring at the baffle blocks.

(2) At the western end of the outfall, the maintenance road once again angles back across the outfall channel (see Incl 2) preventing free access to the pilot channel for flow which is moving down the main portion of the channel. Because of this barrier, water surface profiles extending back upstream are higher than they would otherwise be, further compounding the problem of the hydraulic jump being forced upstream at the railroad bridge.

b. Sediment deposits at the baffle blocks, in the subcritical transition, and in the outfall channel contributed to the improper functioning of the structure. In a visit to the site on October 4, 1980, Mr. Quintana of the COE observed the following:

(1) In the area of the baffle blocks, sediment had been deposited to a depth of 5 feet. It should be noted that the baffle blocks were completely

exposed during the field visit of August 27, 1980, which is an indication of just how rapidly sediment is deposited at this location.

(2) With the exception of the small channel near its south side, the entire transition area downstream of the baffle blocks to approximately station 40+00, was covered by a considerable layer of sediment.

c. Hydraulic performance of the Alameda structure could be improved by:

(1) Removing the maintenance roads which now traverse the subcritical transition and outfall channel.

(2) More frequent removal of sediment deposits in the area of the baffles and subcritical transition.

4. The Alameda Outlet Structure was designed to transition flows from super to subcritical without a fully developed hydraulic jump for a maximum discharge of 44,000 cfs. At maximum discharge with the structure functioning as designed, clearance between the design water surface and low steel at the railroad bridge was calculated at 1.2 feet. The design was based upon a similar transition structure designed for Walnut Creek, California by the Los Angeles District. Upon completion of the design by the Albuquerque District it was submitted to the Los Angeles District for model testing.

5. Model Study

a. In 1957 and 1958 the Los Angeles District (LAD) conducted a model study of the Alameda structure. Results of the testing were presented by the LAD in Report No. 1-102 entitled "Transition Structures for North Diversion Channel, Albuquerque, New Mexico", dated May 1958. After some minor modifications from the original design, the model gave satisfactory results in terms of energy dissipation and flow patterns. It should be noted however that the model was tested with a straight approach channel while the prototype structure is preceded by a curve. The curve is located approximately 580 ft. upstream of the railroad bridge, carries flow at supercritical velocities and changes the direction of flow by approximately 70. Because of the unstable and unpredictable nature of supercritical flow in curved channels, it is probable that without the upstream curve the model's prediction of prototype performance was inaccurate. It is likely that until such time as an accurate model of the structure (including the approach curve) is built and tested, the performance of the Alameda structure will continue to be unpredictable. A new model study will produce the following information:

(1) The effects of channel curvature on flow at the railroad bridge.

(2) What modifications to the prototype are necessary to improve performance if channel curvature proves to be a major factor.

b. Inclosure 2, includes correspondence concerning the model study which gives some insight into the decisions made during and after the model study. Also included in Inclosure 2 is a list of modifications which were incorporated into the prototype design after the model study had been completed. Some of these modifications are substantial, which further supports a requirement for an updated model study of the structure.

c. Any model study undertaken to evaluate the performance of the Alameda Outlet Structure must take into account the increase in runoff potential in the watershed drained by the North Diversion Channel. This increase in runoff potential has been caused by urbanization in the North Albuquerque area. A study¹ prepared for the Albuquerque District gives an indication of the increased discharge that the diversion channel can be expected to carry. This study was an approximate one which was to be followed by a major reassessment of the adequacy of the North Diversion Channel. As of this date the planned reassessment cannot be carried out because of the lack of funding.

6. Summary and Recommendations

a. The following conditions are adversely affecting the performance of the Alameda outlet structure:

- (1) Access roads crossing the outlet structure at various locations.
- (2) Sediment buildup around the baffle blocks in the subcritical transition and in the outfall channel.
- (3) Curvature of the Alameda Diversion Channel upstream from the AT&SF railroad bridge.

b. Optimization of the performance of the structure with no major structural changes would be obtained by removal of the first two conditions as follows:

- (1) Lowering the access roads until they are no higher than the outfall structure invert. This would improve the hydraulic performance of the structure and also improve drainage because of the opening of the pilot channel at the far western end of the outfall.
- (2) Sediment removal from around the baffle blocks and from the downstream transition and outfall channel at frequent intervals.

c. Channel curvature and model study

(1) Because of the high speed channel curve upstream from the railroad bridge in addition to other reasons, a model study is required. The model will determine to what extent the channel curve affects structure performance. In addition, the model can determine the various structural alternatives available to improve performance.

(2) Although a model study is required, up to date accurate information on discharge potential for the prototype is not available. An accurate hydrologic study of the North Diversion channel drainage basin should be an integral part of preparations for a model study. The model study should also include a full assessment of downstream channel conditions, including sedimentation.

¹ "Impact on North Diversion Channel from Concrete Lining of Tributary Channels at Albuquerque, New Mexico" was prepared for the Albuquerque District by Espey, Huston & Associates, Inc. in February 1980.

APPENDIX B

SWAED-PH

10 August 1982

MEMORANDUM FOR RECORD

SUBJECT: North Diversion Channel, Alameda Outlet Structure. Observation of flow during storm of July 31, 1982

I observed the operation of the North Diversion Channel Alameda Outlet structure during the storm of July 31, 1982. My observations were made at or during the peak between 8:00 PM and 9:00 PM. The staff gage immediately downstream from the Santa Fe Railroad Bridge was fluctuating between 10 and 10.5 feet. Flow in the diversion channel peaked at $7400 \text{ ft}^3/\text{s}$ during the storm according to the U.S.G.S.

A hydraulic jump was occurring upstream from the railroad bridge at a skew angle, about 120 feet upstream along the north side of the channel (outer side of the approach curve in the channel) and about 150 feet upstream along the south side.

All or most of the flow was flowing through the north bay of the two bay bridge. Debris in the water at the mid-point of the south bay, just upstream from the bridge, was stationary. Debris along the south wall was moving upstream to a point just before it hit the incoming water at the hydraulic jump. At this point the debris swirled toward the center of the channel and joined the flow in the north side of the channel. There was a definite upstream flow on the south side of the channel.

Downstream from the bridge there was considerable turbulence and wave action for a considerable distance. Velocities appeared to be higher on the north side of the channel. There was slight eddying where the concrete wall flares out and ends on the south side.

Mr. Larry Blair, AMAFCA, arrived at the site, mentioned a flow disturbance or turbulence at the ramp into the channel upstream from the Camino Arroyo inlet and we drove over to observe it.

A standing wave forms at a skew at the downstream end of the widening for the ramp. The water spreads out at the upstream end of the widening, then hits the side slope where the water is forced back into the normal section (25 ft bottom, IV:2H side slope). The standing wave has the semblance of a hydraulic jump but flow continues downstream in the supercritical regime. Critical slope for the observed flow of $7400 \text{ ft}^3/\text{s}$ is 0.0014 ft/ft. The slope of the channel is 0.0032 ft/ft.

SWAED-PH

10 August 1982

SUBJECT: North Diversion Channel, Alameda Outlet Structure. Observation of flow during storm of July 31, 1982

The standing wave would encroach on the freeboard at the design discharge of 44,000 ft³/s, the extent unknown, and could possibly cause overtopping of the levee.

ELIAS M. QUINTANA
Hydraulic Engineer
Planning Branch, Hydrologic Engr. Sec.

END

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